Are we significantly oversizing domestic water systems?

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Abstract

There is growing dissatisfaction with the DCWS volume flow rates predicted by the UK sizing methods, particularly for sizing incoming mains and pressure boosting sets. The consequences of oversizing include increased heat loss from domestic hot water systems, thus reducing their energy efficiency, and difficulties in avoiding domestic cold water reaching unacceptably warm temperatures particularly in high rise buildings due to the slower throughput.

The aim of this paper is to present measured domestic water volume flow rates and compare them with those obtained by calculation in order to investigate the magnitude of oversizing. The study revealed that the measured flow rates are on average just 20% of those calculated however BS EN 806-3 is by far the most accurate of the three methods.

Keywords DCWS, volume flow rate, probability, oversizing

1.0 Introduction

Domestic cold water service (DCWS) systems for supplying water for drinking, cooking, washing and WC flushing are an expected feature of our modern industrialised society. However, over recent decades a growing awareness regarding the need to reduce water and energy consumption has led to significant changes in the amount of water used for various purposes. For example, manufacturers of domestic washing machines are obliged to show both the water and energy consumption for each of their products so that buyers have the information to enable them to choose efficient models if they wish.

Periods of UK water shortages have also raised awareness amongst the public and aided in their acceptance of dual and low flush WC's. It is perhaps not surprising then that DCWS sizing methodologies which date back decades now result in significantly oversized systems.

This investigation recorded the incoming DCWS volume flow rates at two multi story residential blocks and compared the measured peak flow rates against the flow rates suggested by the three currently most commonly used UK sizing guidance documents. Secondary data, supplied by a leading UK manufacturer of DCWS pumping equipment, has been used to validate the data gathered and enables firm conclusions to be drawn from the study.

2.0 Reasons why oversizing is a problem

Oversizing of DCWS is detrimental to projects not just because of the obvious capital cost implications but also because it leads to reduced water quality and potential problems with the operation of booster sets.

As discussed in a recent paper (1) oversizing pipework reduces water velocities which means that the water remains in the distribution pipework far longer than is ideal for health and hygiene reasons. This problem is most extreme in tall buildings where the domestic cold and hot water pipework runs within the same riser space resulting in undesired heating of the cold water.

Another issue with oversizing domestic water systems for tall buildings is that the booster, required to increase the pressure of the mains water in order to supply water to every floor, is also oversized. This can lead to control problems, pressure fluctuations and premature pump failure. Commonly booster manufacturers encourage engineers to fit booster sets combining many smaller pumps into one booster set in order to minimise the consequences of oversizing and ensure reliable operation. Would it not be better to more closely match the design to the actual demand, or in other words, narrow the design to operation gap?

2.1 Developments in DCWS sizing

Many of the established guides for the sizing of DCWS have changed relatively little over the years. For example, the American Society of Heating, Refrigerating and Air Conditioning Engineers publish domestic water load estimation guidance in ASHRAE Applications (2) which is based upon research conducted over 70 years ago (3).

There has been some indication that current sizing methods could lead to overestimation of water demand. A team in Hong Kong (4) calculated a theoretical water design volume flow rate using a ‘fixture unit’ method, which probably followed the ASHRAE guidance, although this is not specifically categorised in the article. This information was then compared with theoretical data from a model developed using measured data from 1300 households in 14 typical high rise buildings in Hong Kong.

When the two data sets were compared it was found that the water demand predicted from analysis of the measured data method was around 50 – 60% of that calculated using the ‘fixture unit’ estimation method, which was said to be the current design practice adopted for high rise residential buildings in Hong Kong. Results from their study (4) are shown in Figure 1 overleaf.

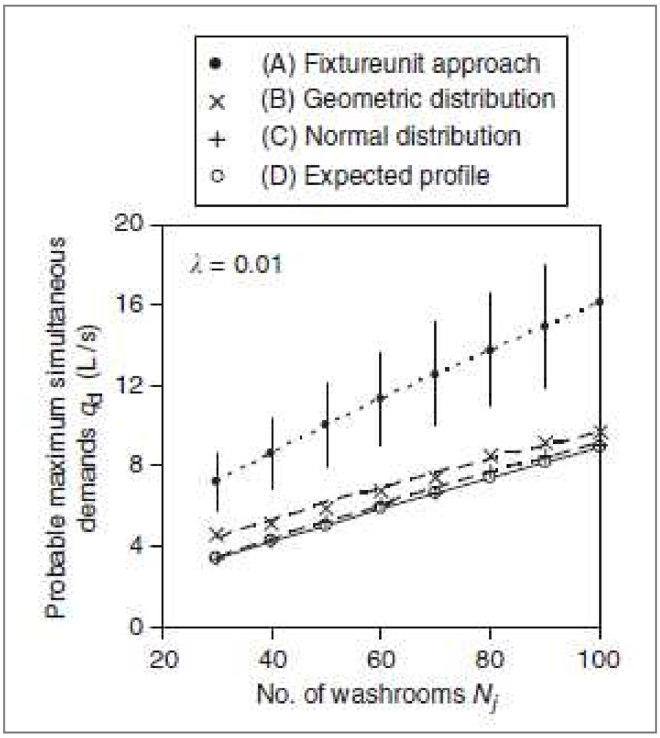

Figure 1 Probable maximum simultaneous demands of a number of example domestic washrooms (4)

In a study by a Brazilian team (5), similar results were found, showing that the design flow rate obtained from a model based on measured data was found to be 23% lower than a flow rate obtained from using Brazilian standards on estimating water demand.

The studies highlight that as an emphasis on water conservation has increased, and has made more of an impact on the technological evolution of building services, the actual demand of domestic water has reduced. In countries where water is a more precious resource, the effect of public awareness schemes has been most pronounced. In the UK, where water is arguably more abundant, there have been steps taken towards reducing water usage within dwellings, as described in the Code for Sustainable Homes (6) and current building regulations (7). This suggests that attitudes have changed, or may be changing, with regards to water usage, and suggests that subsequent investigation and modification of UK specific guidelines may be necessary.

There is some argument about which theoretical method of estimating water demand is most accurate. A study from 2007 (8) used a Monte-Carlo method of simulation, which involved assuming that usages of water were a random activity, and assigning a probabilistic formula to determine instances of usage. The Brazilian study (5) also used this method, but built upon the random instances of usage with the application of fuzzy logic, which was used to determine the duration of usage. It is described that this method allowed for the inclusion of variables through the formation of a fuzzy matrix. For example, if the weather is cold and the air temperature is low, and the occupant has a shower early in the morning, then the duration of the usage will be longer than if the user is showering later and the weather is warmer. It is these nuances in the variables used in the fuzzy logic simulation that may make it a more accurate judge of instantaneous loads.

In other countries, the domestic water load estimation guidance has been directly challenged, and subsequent research and development has influenced the production of more accurate resources. For example, researchers from The Netherlands (1) sought to analyse current Dutch guidance on drinking water supply systems, which were based on measurements collected between 1976 and 1980. They state that the old guidelines generally overestimate peak demand values due to an increased range of available appliances and changes in the behaviour of building occupants since the guidance was devised. The importance of accurately estimating peak demand values is highlighted as poorly designed and oversized systems are less efficient thus more expensive, but can also cause stagnant water, possibly leading to increased health risks. By using data gathered from a range of buildings of different water usages such as flushing a toilet or washing hands, the team constructed a stochastic model called SIMDEUM, standing for Simulation of Water Demand, an End-Use Model. The research highlights that in designing a domestic water distribution system, the peak value of the total water demand, referred to in their report as the MMFcold, or maximum momentary flow of cold water, is of great importance. The research uses a procedure developed in 2010 (9) to derive design demand equations for the peak demand values of DHWS and DCWS in both residential and non-residential buildings. The study found a good correlation between their demand equations and measured patterns of use, which was much more accurate than the current Dutch guidance, indicating that their calculations were reputable.

Using these demand equations, the Dutch study (1) found that the results of their simulations matched measured values of peak water demand, and that the pipe diameters in the systems they studied were considerably larger than necessary. They hypothesise that the issue of oversizing may be present in other countries, and state that their SIMDEUM model could be easily adapted for use in other countries when specific information of users and appliances is available. Interestingly, they also note that although international guidelines on water demand estimation do not exist in the public domain, international knowledge exchange will strongly contribute to better understanding of domestic water use. The study (1) concluded by stating that the design demand equations developed by the team have been adopted in a revised version of the Dutch guidelines, which were released in 2013, meaning that ‘The Netherlands is a frontrunner, being the only country in the world with specific regulations for water use in non-residential buildings. Therefore they are a step ahead in the transition to more sustainable buildings.’

2.1 UK sizing guidance

In 2000 Britain began the process of standardising the guidance for DHWS with the European Union (EU). BS EN 806 part 1 'Specifications for installations inside buildings conveying water for human consumption' (10) was published in November 2000, however, this didn't offer advice for system sizing. Consequently BS 6700 'Design, installation, testing and maintenance of services supplying water for domestic use within buildings and their curtilages' (11) remained as the UK British Standard for DCWS sizing until BS EN 806 part 3: 'Pipe sizing – simplified method' (12) was published in April 2006.

The harmonised EU standard BS EN 806 part 3 (12) presents a simplified pipe sizing method for 'standard installations'. It is explained in section 5.1 that 'this method can be used for all type of buildings, which do not have measurements, which highly exceed the average.' In section 5.2 it explains that 'the designer is free to use a nationally approved detailed calculation method for pipe sizing' if they deem it appropriate and in Annex C BS 6700 (1997) is listed as the national pipe sizing method for the United Kingdom. Later in 2006 a revised version of BS 6700 was issued.

The latest edition of CIBSE Guide G (13) was published in 2004 and so still refers readers to BS 6700 (1997) and to the Institute of Plumbing's (IoP's) 'Plumbing Engineering Services Design Guide' (14). It explains that although the IoP's guidance is based on BS 6700 data, some variation may occur in the calculated values owing to differences in factors such as the duration of usage for outlets and the average time between usages.

All the three sources of UK DCWS sizing guidance listed above use the same technique. For each outlet type the flow rate, duration and frequency of use are considered in order to arrive at an allocated number of 'Loading Units' (LU). The loading units for outlets are then summed and converted to a volume flow rate using a chart.

The IoP guide provides more explanation and detail about the derivation of its loading units and it also provides loading units to account for different frequencies of use (Low, Medium, High). Low use is calculated for a period of 20 minutes between each use and is recommended as being 'appropriate for dwellings………' i.e. where the outlet is used by only a few people. Medium is calculated for a period of 10 minutes and is suitable for outlets used by 'a larger group of people, as and when they require on a random basis with no set time constraint….'. High use is for a period of 5 minutes between uses and is applicable for outlets used by large numbers of people over short periods of time e.g. theatres or concert halls.

Similarly, there is a choice of a standard LU value of 1.5 for wash hand basins in BS 6700 (11) or 3 if installed in a location that will experience peak periods of use, e.g. schools. This is, however, the only example where building usage can be factored into the selection of LU's using BS 6700 (11), and there are no such examples at all in BS EN 806-3 (12), and so the IoP guide (14) appears the most flexible of the three methods.

BS 6700 (11) and the IoP guide (14) have very straight forward conversion charts whereas BS EN 806-3 (12) uses a different approach to construct Figure B.1 (see Figure 2) in order to relate the total LU's to a design flow rate. Figure B.1 considers the largest single outlet (indicated by note 3) in a project (building wing, floor or branch) and, below 300 LU's gives a different curve for each. This suggests that it may be able to offer a closer relationship between total LU's and system flow rate, particularly on smaller projects.

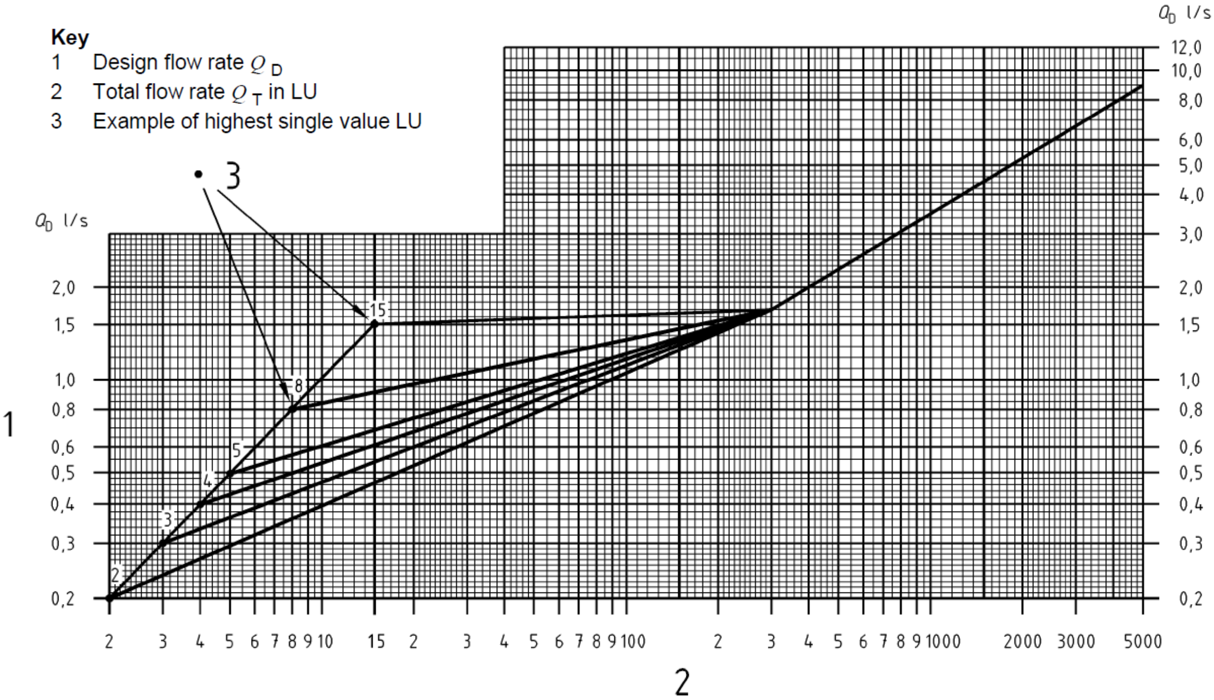

Figure 2 BS EN 806-3 (12) Fig B.1 Loading units to design volume flow rate

Section 2.9.2 of CIBSE Guide G (13) states that probability theory 'is based upon the likelihood of situations occurring and therefore its predictions will be exceeded on rare occasions. In fact, it is a requirement of this method of calculation that a limit is set on the time when a calculation is expected to be exceeded. This has often been taken as 1% which proved to be reliable in that it has not led to the under-design of pipe sizes.'

It is therefore appropriate to compare the design flow rate predicted by the three probability methods outlined above with the measured flow rate which is exceeded for 1% of the time. This analysis has been included within this study for the primary data and a red line has been added to each of the results graphs to display the 1% exceeded flow rate.

2.2 Sizing methodologies included in this study

In this study DCWS flow rates for two multi story residential developments were recorded and these were compared with the design flow rates predicted by each of the following three UK sizing guides.

BS EN 806-3 (12) is included because it is the current European Standard and the most recently introduced of the three methods.

It is conceivable (but not appropriate) that Engineers could choose to use the UK nationally agreed sizing method BS 6700 (11) for these projects and so this too will be included in the analysis.

Some Engineers prefer to use the IoP guidance (14), believing it to be more flexible and therefore accurate and for this reason it has been included as the third sizing method for comparison.

The low frequency loading units have been used where choices were available.

2.3 Method

Your Homes Newcastle, the social housing division of Newcastle City Council, kindly gave permission for the DCWS flow rates to be monitored at two of their properties.

Shieldfield House is a 26 storey residential block consisting of 125 two bedroom flats, located on Barker Street in Newcastle upon Tyne. The building was completed in 1966 and has recently been renovated having benefitted from internal 'Modern Homes' improvements (15). The building is restricted to residents over 55 years, and as such has many retired occupants.

Figure 3 Photograph of Shieldfield House (16)

King Charles Tower is an apartment block in Shieldfield, Newcastle upon Tyne and consists of 60 two bedroom flats and 30 single residences. The block is 43m tall (17) and was completed in 1961 although it has also benefitted from modernisation of individual flats under the modern homes scheme. The block is owned and operated by YHN and houses a range of occupants of various ages, with a mix of employed and unemployed residents.

Figure 4 Photograph of King Charles Tower (17)

According to council records both buildings were fully let to tenants although it couldn't be verified how many people were resident at the buildings during the measurement period.

Flats in both buildings have the following outlet types installed in each flat:

- Shower
- WC
- Wash hand basin
- Bath
- Kitchen sink

Washing machine and dishwasher numbers could have only been ascertained by a survey or return of questionnaire from each flat which time constraints precluded and therefore these were excluded from the analysis. This may mean that the degree of oversizing reported is underestimated.

Both buildings use electrically heated DHWS storage vessels within each flat fed from the incoming DCWS supply. In practice it is usual to add the DHWS LU to the DCWS LU to derive the overall incoming main DCWS flow rate into the building and this, therefore, is the approach taken within this study. Hot water LU's were allowed for each outlet type with the exception of the WC.

	BS EN 806-3 (LU's)	**BS 6700 (LU's)**	**IoP (LU's)**
Shieldfield House (125 flats)	2375	4625	2375
King Charles Tower (90 flats)	1710	3330	1710

Table 1 Total loading units for each method

The Loading Units were converted to volume flow rates using the appropriate charts:

BS EN 806-3 (12)	Figure B.1
BS 6700 (11)	Figure D.1
Institute of Plumbers (14)	Graph 3

	BS EN 806-3 (l/s)	**BS 6700 (l/s)**	**IoP (l/s)**
Shieldfield House (125 flats)	5.65	20.5	11.5
King Charles Tower (90 flats)	4.8	16.5	10.5

Table 2 Design volume flow rates for each method

The divergence in predicted volume flow rates is evident in table 2 above where there is a factor of at least 3.44 between the BS 6700 (11) and BS EN 806-3 (12) values.

DCWS flow rate measurements were recorded for a period of one week at both buildings using Bell Flow Systems BFU-100M Ultrasonic Flowmeter with the transducers installed in a 'V' configuration as illustrated below.

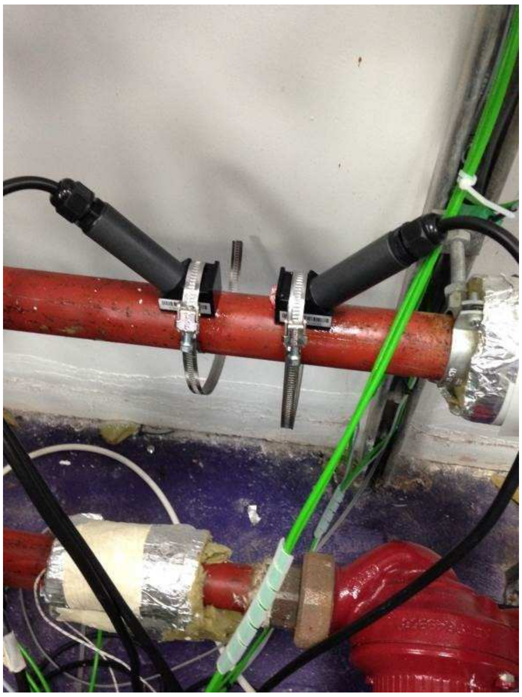

Figure 5 Image showing the installation of transducers

A Tinytag TGP-0804 Current Input Data Logger was used to record the DCWS flow rate at a frequency of 10 seconds.

The volume flow rate exceeded for 1% of the sample period was later determined for each building and is included as a broken horizontal line on the following results graphs (Figures 6 - 11).

2.4 Results

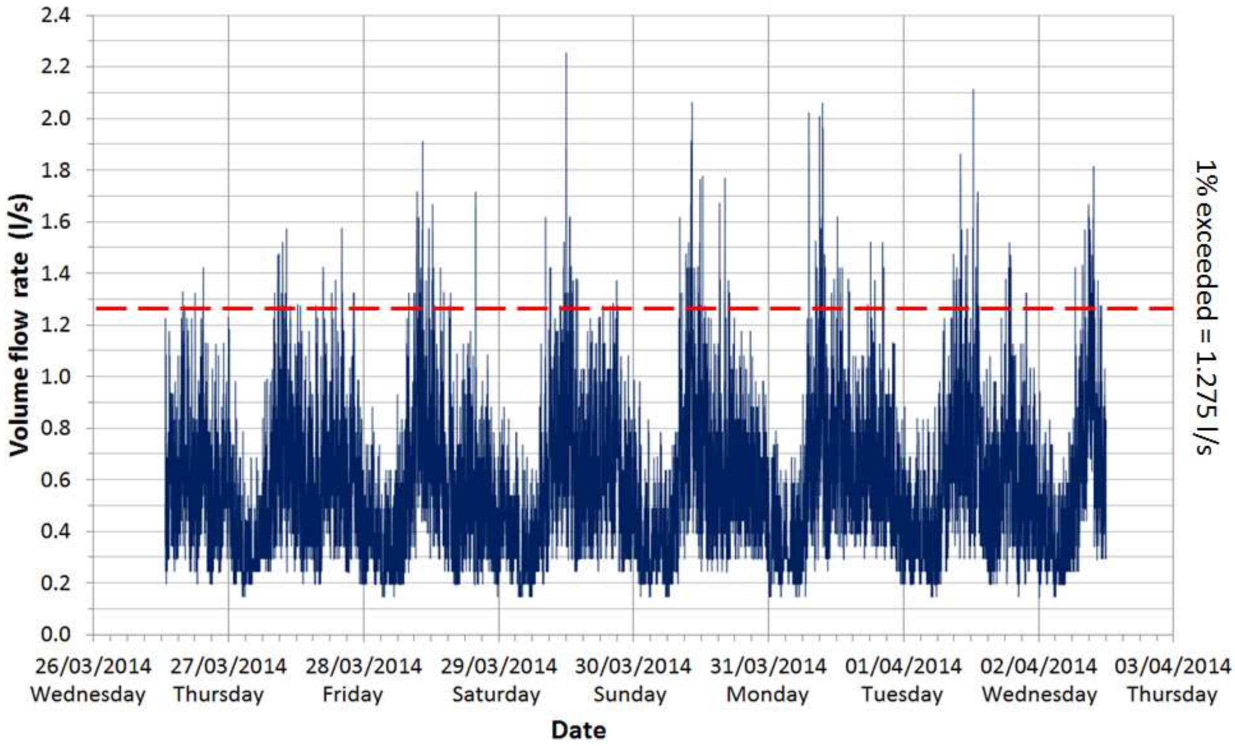

Figure 6 Shieldfield House week long DCWS volume flow rates

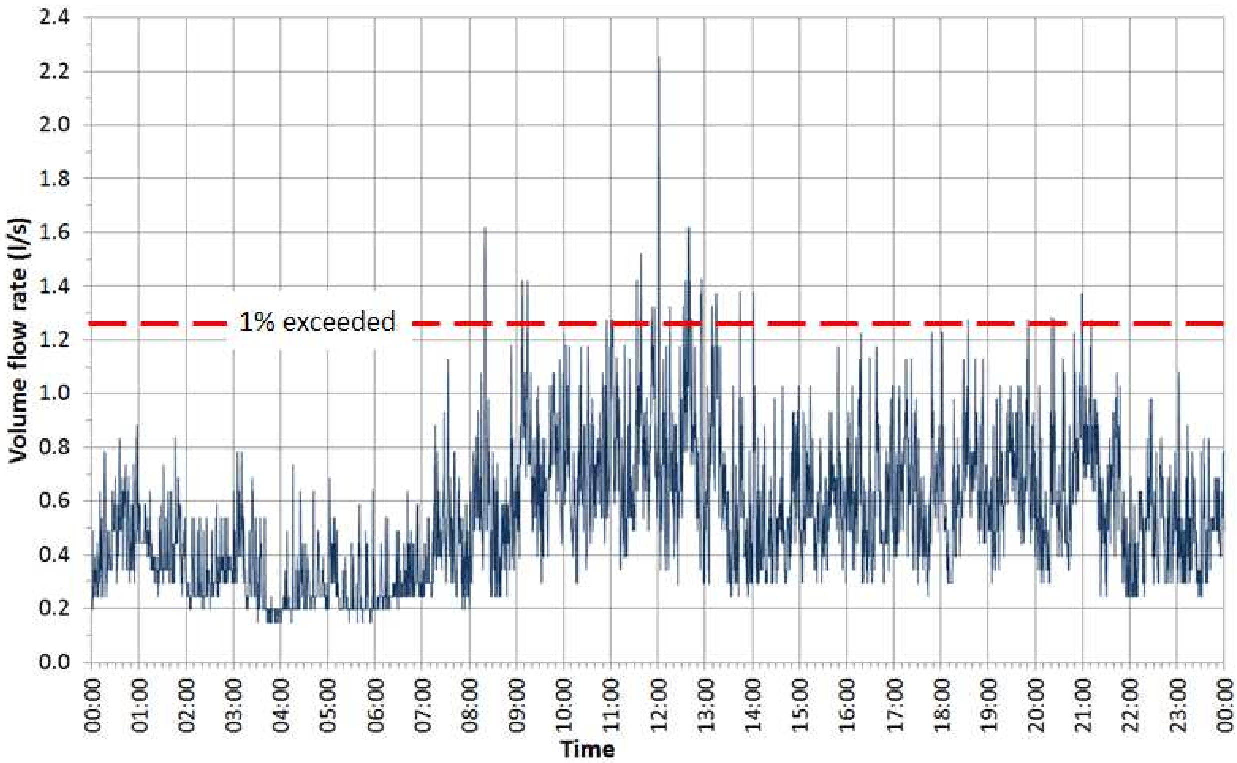

Figure 7 Shieldfield House peak day DCWS volume flow rates

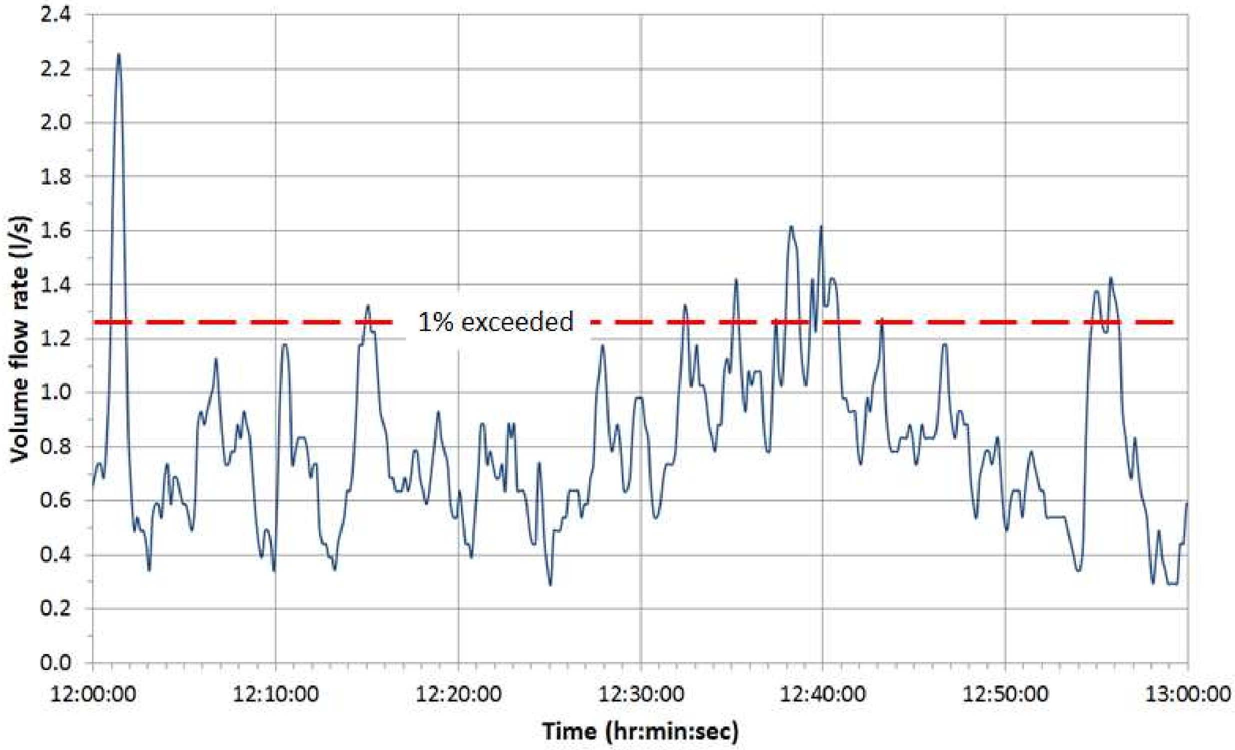

Figure 8 Shieldfield House peak hour DCWS volume flow rates

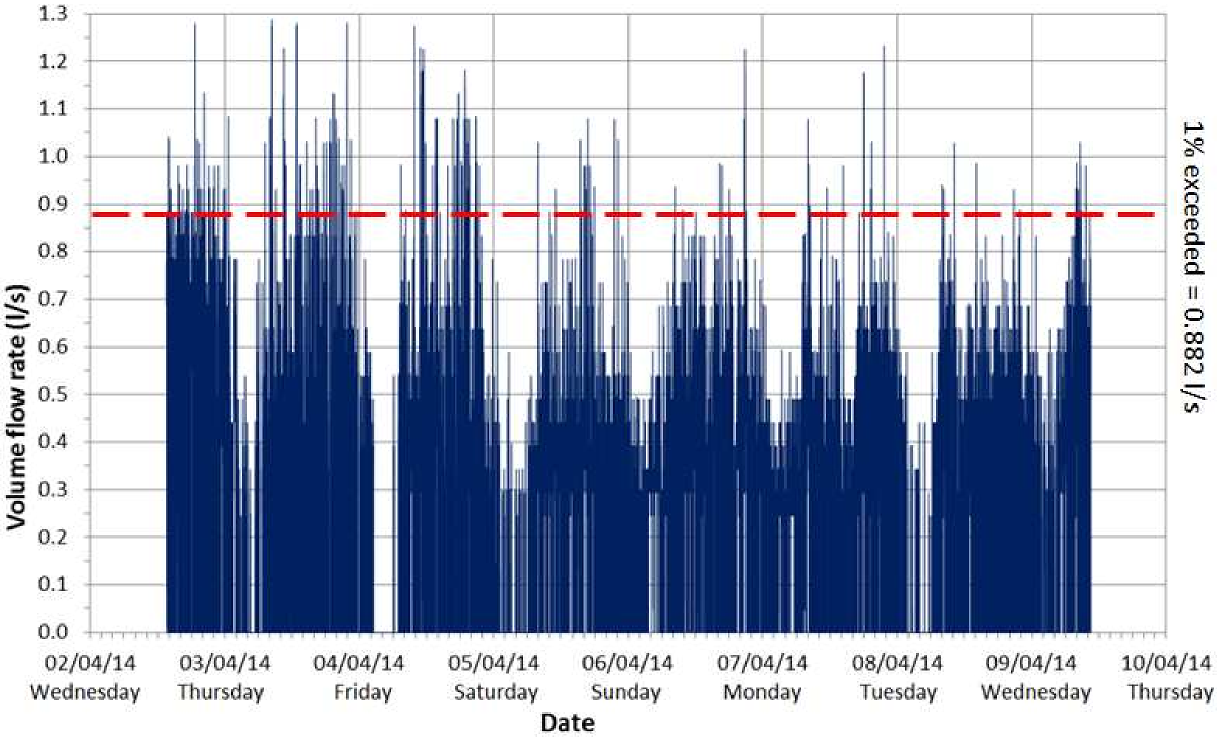

Figure 9 King Charles Tower week long DCWS volume flow rates

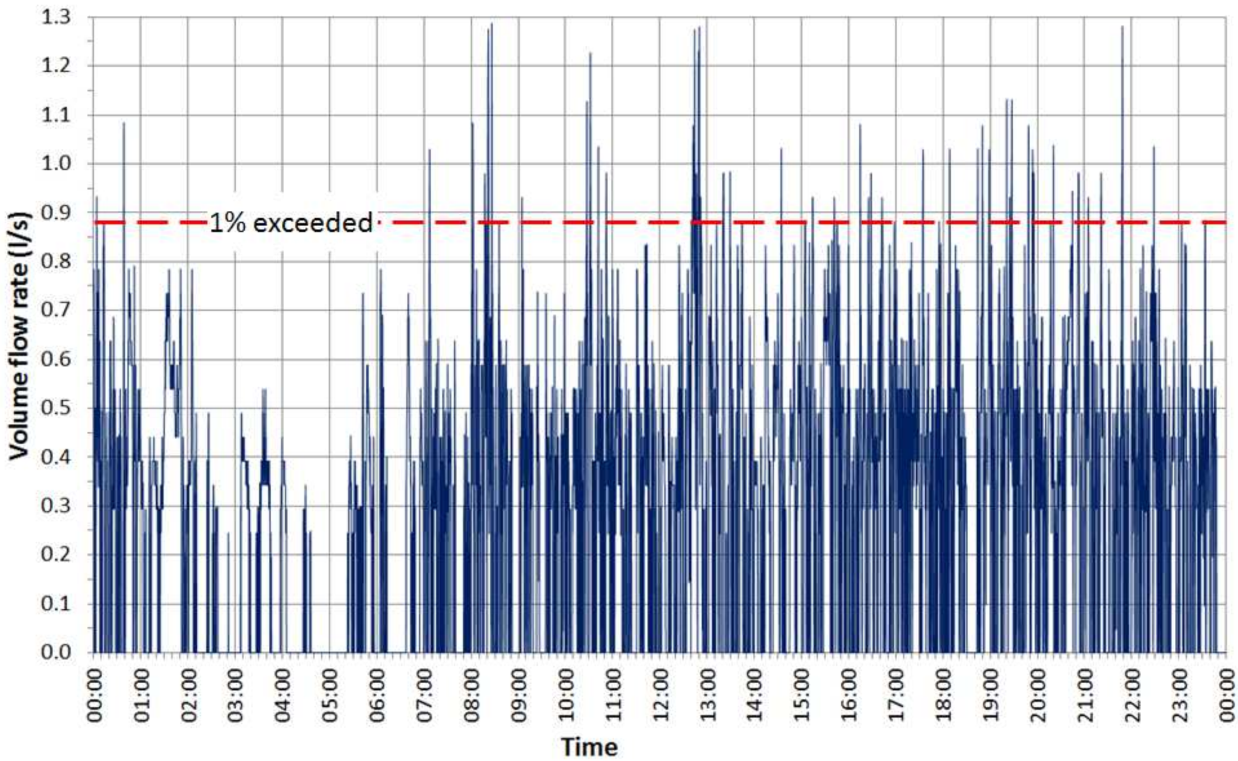

Figure 10 King Charles Tower peak day DCWS volume flow rates

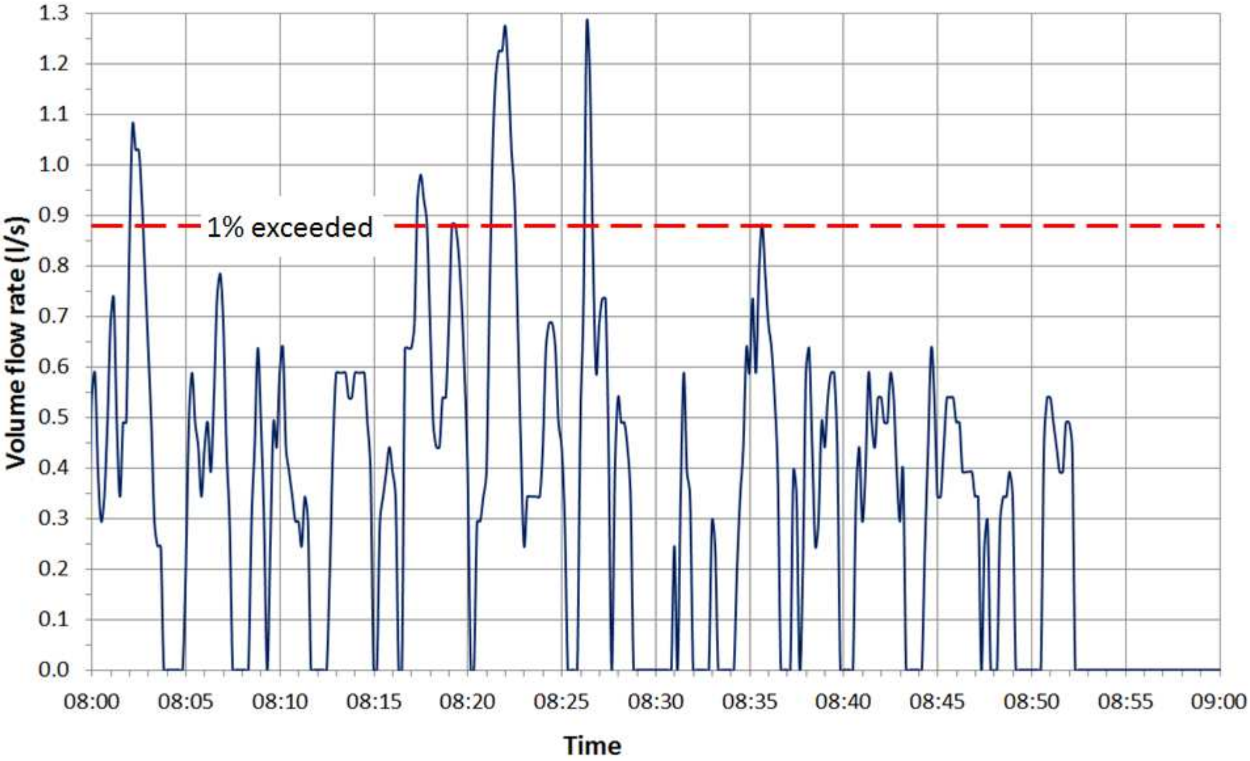

Figure 11 King Charles Tower peak hour DCWS volume flow rates

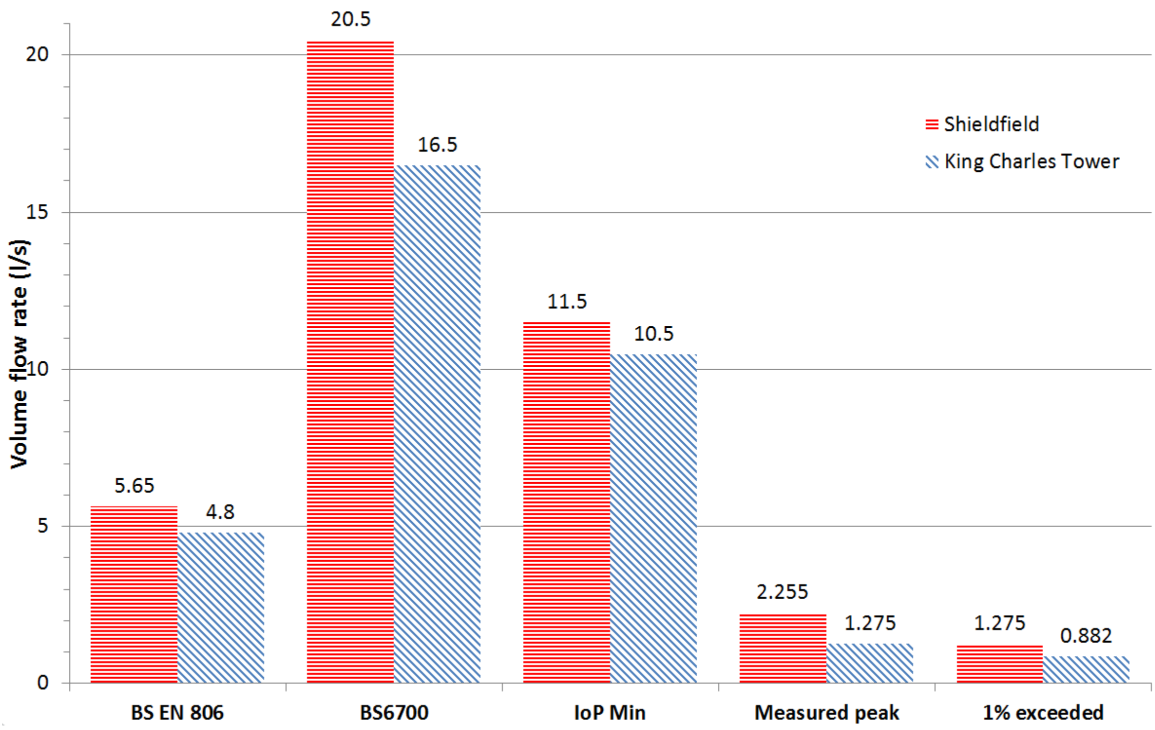

Figure 12 Theoretical vs measured volume flow rates

Table 3 below sets out the percentage of oversizing calculated for each sizing method against the peak measured volume flow rates calculated using the data shown in Figure 12.

Building	Measured volume flow rate	BS EN 806-3	BS 6700	IoP
Shieldfield House	Peak measured (2.255 l/s)	151%	809%	410%
King Charles Tower	Peak measured (1.275 l/s)	276%	1194%	724%

Table 3 Percentage over the measured peak volume flow rate

CIBSE Guide G (13) confirms that the probabilistic sizing methods are designed to return a design flow rate which is exceeded for 1% of the time. It could be argued therefore that it is more appropriate to compare the degree of oversizing not against the measured peaks but rather against the measured volume flow rate exceeded for 1% of the sample time.

Table 4 below sets out the percentage of oversizing calculated for each sizing method against the volume flow rates exceeded for 1% of the sample period.

Building	Measured volume flow rate	BS EN 806-3	BS 6700	IoP
Shieldfield House	1% exceeded (1.275 l/s)	343%	1508%	802%
King Charles Tower	1% exceeded (0.882 l/s)	444%	1771%	1090%

Table 4 Percentage over the 1% exceeded volume flow rate

2.5 Secondary data

The primary data reported above was combined with secondary data collected by a leading independent UK manufacturer of fluid pumping equipment to the Building Services, Process and Water Industries. The company has been gathering water consumption data for a wide range of building types for several years using a clamp on ultrasonic flow meter in order to better understand the environments in which their equipment is operating. This secondary data is used here to increase the sample size and validate the primary data from this smaller, time limited study.

Table 5 below displays information about each building for which secondary data is presented. The buildings are listed in rising order of the number of flats or apartments within the building.

Building name	**Number and type of accommodation**	**DCWS outlet types**	**Total Loading Units (Hot and cold)**		
			BS EN 806-3	**BS 6700**	**IoP (Min)**
Kingsmead House	22 two bed flats	whb & wc x2, bath, shower, kitchen sink, wm, dw	528	990	528
Westway M	27 two bed flats	whb & wc x2, bath, shower, kitchen sink, wm, dw	648	1215	648
The Artworks	33 two bed flats	whb & wc x2, bath, shower, kitchen sink, wm	627	1221	627
Gallions Point	45 two bed flats	whb, wc , bath, shower, kitchen sink, wm	855	1665	855
Lowry Centre	154 two bed flats	whb & wc x2, bath, shower, kitchen sink, wm, dw	4020	7530	4020
	12 three bed flats	whb & wc x3, bath, shower, kitchen sink, wm, dw			
Westway A to L	50 one bed flats	whb, wc , bath, kitchen sink, wm	4070	7700	4070
	130 two bed flats	whb & wc x2, bath, shower, kitchen sink, wm, dw			
Glasgow Harbour	255 one bed flats	whb, wc , shower, kitchen sink	2295	3570	2295

Table 5 Secondary data building information

List of abbreviations used in table 5 above:

whb wash hand basin

wc water closet (toilet)

wm washing machine

dw dishwasher

Figure 13 below displays the measured peak volume flow rate against the number of flats per building for both the primary and secondary data. The primary data points are marked with triangles and the secondary with crosses.

There is variance around the line of best fit as would be expected given the different size of flat, number of outlets and variations in building usage. The graph does, however, clearly show that the primary and secondary data are of the same magnitude and follow the same trend. It has therefore been deemed reasonable to include the secondary data within this study.

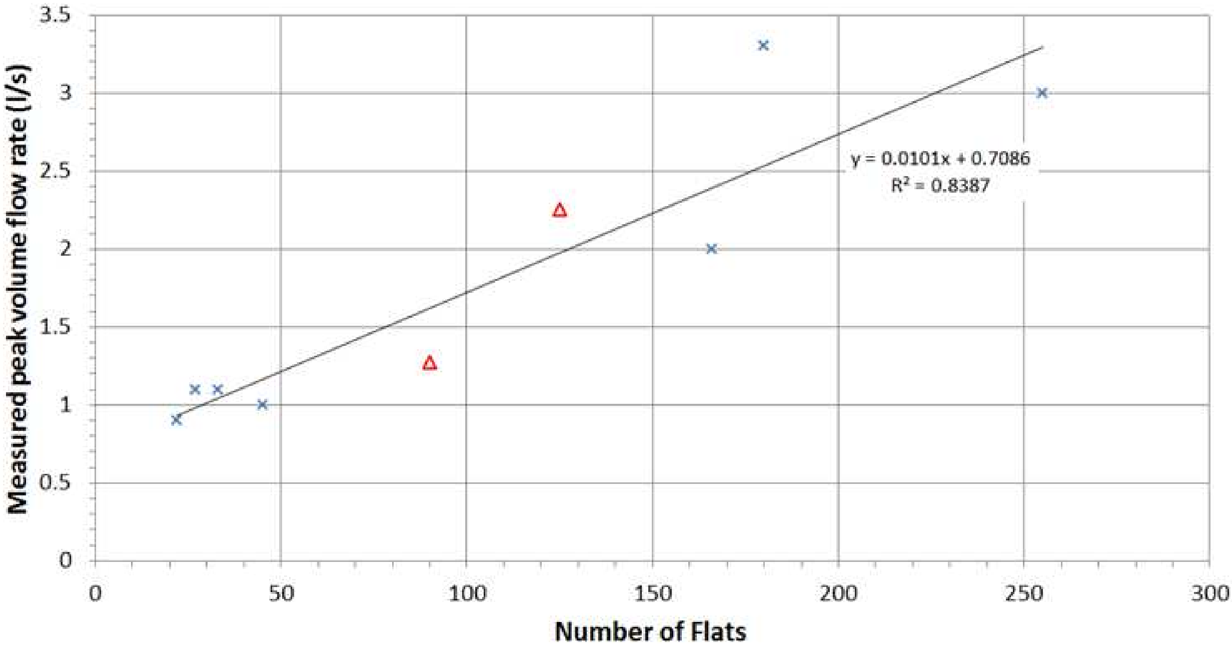

Figure 13 Primary and Secondary data measured peak volume flow rates

Figure 14 displays the design flow rates predicted for the nine buildings alongside the measured peak volume flow rates. The two buildings for which primary data are presented are King Charles Tower and Shieldfield House.

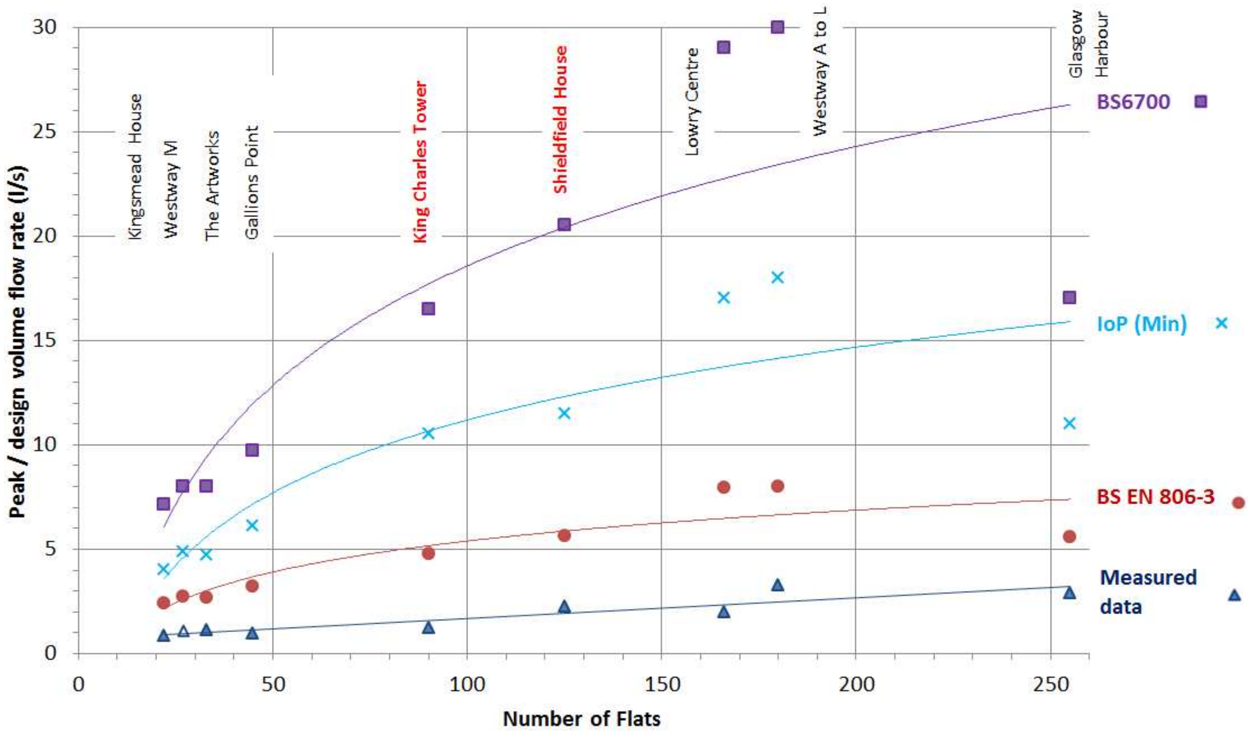

Figure 14 Design and measured flow rates

Figure 15 displays the percentage over (or under) sizing for each building and sizing each method.

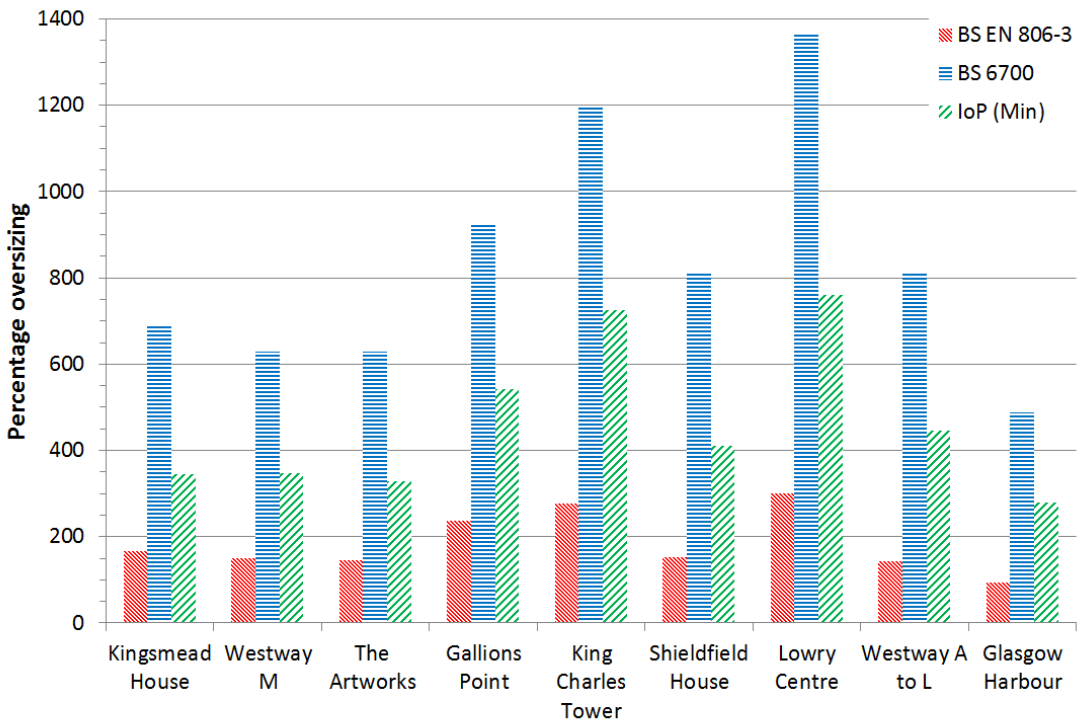

Figure 15 Percentage oversizing compared to the measured peak volume flow rate

Figure 16 below displays the minimum, average and maximum oversizing across the datasets for these nine projects for each sizing method.

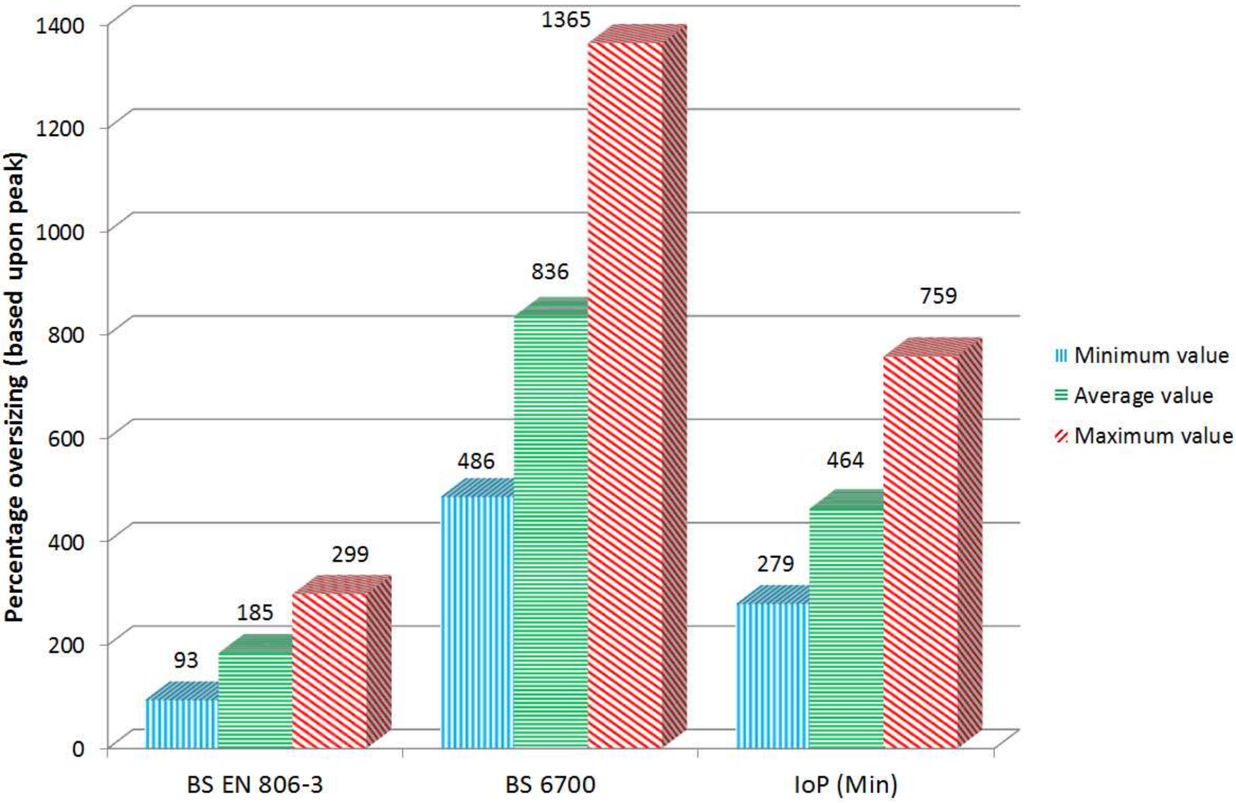

Figure 16 Min, average and maximum oversizing by method

2.6 Discussion

It is evident that BS EN 806-3 (12) is the best of the three UK sizing methods for predicting DCWS volume flow rates on two grounds. Firstly, the predicted volume flow rate is closer than those predicted by the other methods for all buildings in the study. Secondly, the gradient of the line of best fit is almost parallel to that for the measured data (see Figure 14). This should mean that BS EN 806-3 (12) can be used for larger residential projects without excessively oversizing the pipework.

The same cannot be said of the IoP (14) and BS 6700 (11) methodologies both of which seem to indicate that the margin of error will tend to increase proportionate to the size of the development.

Figure 17 below has been constructed using the charts provided by each sizing method to convert loading units to volume flow rates. The greater level of diversity applied by the BS EN 806-3 (12) method is evident in both Figure 14 and Figure 17.

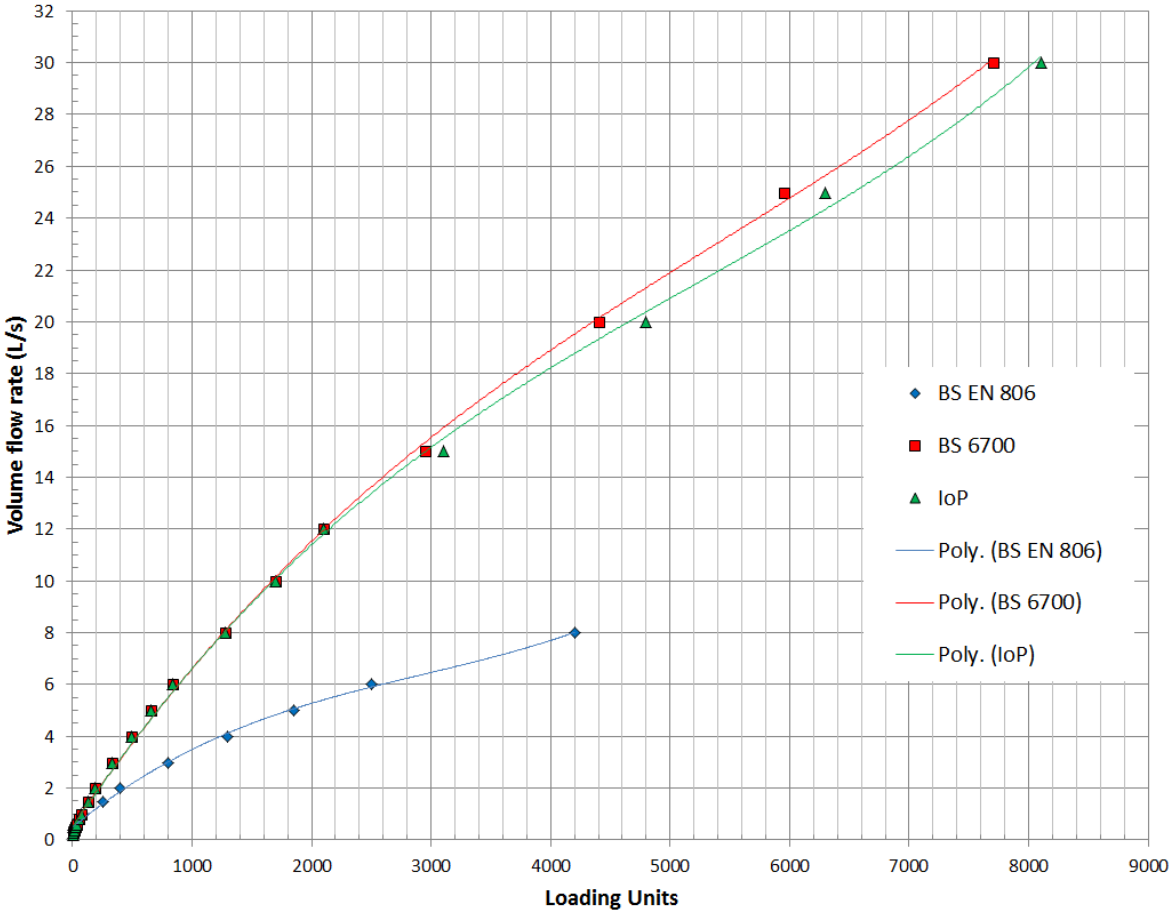

Figure 17 Flow rate to LU comparison

Figure 14 shows that the Glasgow Harbour development of 255 single bedroom flats has data points well below the trend lines for all three sizing methods. This is due to the difference in outlet types present, specifically there were no baths fitted within these flats. The measured peak volume flow rate is however only slightly below the measured data trend line which perhaps indicates that showers were commonly used in the other buildings in which there was a choice of a shower and a bath.

It is also worth noting that the sizing methodologies aim to return a design flow rate which will be exceeded for typically 1% of the time as previously discussed. Therefore in reality the percentage oversizing is more correctly reflected by the results shown in Table 4. The full data sets necessary to calculate the volume flow rate exceeded for 1% of the time were not available for the secondary data set and so this analysis could only be carried out on the primary data. However, for the primary data the average increase in oversizing predicted by considering the peak rather than the 1% exceeded value was 53.2% for King Charles Tower and 103.3% for Sheildfield House.

3.0 Conclusions

BS EN 806-3 (12) is clearly more accurate at predicting DCWS volume flow rates, at least for residential projects, than the other commonly used UK sizing guidance. As a consequence it should result in DCWS being significantly less oversized than has historically been the case. There is still a significant safety margin between the design and measured peak flow rates and so engineers should not hesitate to use this guidance for similar projects.

The findings clearly show that the design flow rates returned by the IoP (Min) guide (14) led to more than double the oversizing resulting from the use of BS EN 806-3 (12) whilst those by determined by BS 6700 (11) were very significantly oversized.

These findings should be welcome news for all Building Services Engineers as we aim to narrow the design to operation gap.

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